Control System and Routing Network under Vehicle-to-Vehicle Communication

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Abstract. This paper first studied platooning in vehicle-to-vehicle communication. Road safety has always been a bit problem in our society, driving with help of platooning control system becomes necessary. This paper compared different methods and tried to get the minimum driving gaps between vehicles depending on driver preference, car size, current speed limit and so on. After evaluating car platooning, this paper studied further information about road networking by analysing different routing network techniques. Graph Attention Network (GAT), Generalized Value Iteration Network (GVIN), Multi-Agent Routing Value Iteration Network (MARVIN). Either method have pro and cons, Marvin has generally good performance and a relatively low price. With the development of vehicle communication, MARVIN could be the main field because of its future potential.

Keywords: V2V, V2X, V2I, PLATOON.

1. Introduction

Vehicle-to-vehicle communication (V2V) based on high-frequency technologies implements a communication network currently used mainly in traffic security. It is usually developed as part of the intelligent transport system (ITS) [1]. There are many specific words to describe the standard and regulations for vehicle communication. (i.e. IEEE, ASTM). In general, V2V has essential improvements for autonomous driving in the future.

The remainder of this paper is structured as follows: Section II identifies the current challenges for vehicle-to-vehicle communication. Section III illustrates perspectives about V2V communication and communication protocols. Section IV presents the PLATOON control system. Section V compares the route networking difference based on the method listed by other researchers. Section VI is the conclusion of this paper.

Many perspectives were taken to analyze the improvement of the vehicle safety system competitively. Moreover, we focus on the different impacts of the Global Positioning System (GPS), Inertial Navigation System (INS), and Light Detection and Ranging (LIDAR) for achieving vehicle-to-vehicle communication. In conclusion, we will focus on the main advantage and disadvantages of V2V algorithms and the future scope this technology could achieve.

2. Current challenge

There were 51 road travel facilities per 1 million inhabitants in the EU in 2021. Road safety is also the main challenge for vehicle-to-vehicle communication., road abstract, other errant vehicles, component failure etc. In this situation, the vehicle should receive emergency warning messages and make a quick response to this emergency depending on how relevant the target vehicle is. During data transformation, the signal noise ratio should be filtered and managed to work when many vehicles connect to the network at the same time. Moreover, personal information should not be disclosed during vehicle-to-vehicle communication. In addition, communication data should be encoded to avoid potential cyber-attack.

To go to the next stage internet to vehicle, the challenge is the logistic ride-sharing business. Therefore, one of the major research challenges for the Internet of Vehicles would be the technical challenge, the vehicle should have a better legacy and data rate. Real-time communication is needed

in designing efficient and intelligent routing management techniques. When V2V communication has become more popular, legality will be discussed. The responsibility boundary will distribute between the driver and auxiliary system.

3. Related wireless communication technology

There are many research works about vehicle-to-vehicle communication from several perspectives: road safety, light performance, and transmission safety.

Vehicular Ad Hoc Networks (VANET) concept is developed by vehicle networking. The connection between the hubs is important and it can prevent blind danger and real-time traffic conditions. However, the hub connection and sending information between the hub is the most string issue. VANET became a basic concept of ITS and mentioned frequently in recent research studies. Figure 1 shows VANET real-life simulation.

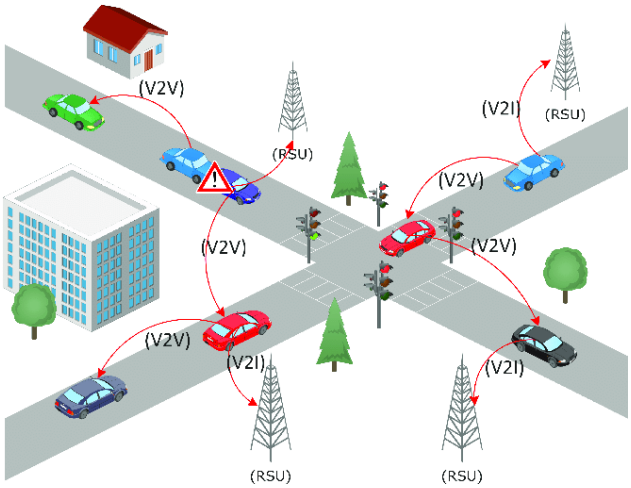


Figure 1. Vehicular Ad Hoc Networks [2]

Dedicated Short Range Communication (DSRC) is a wireless communication technology popularly used in ITS, mainly in V2V and Vehicle to Everything (V2X) communication. With the characteristic of high data transmission rate and reliability for a large amount of VANET in 1000 meters range.

DSRC has different standards between Europe and FCC(US). Authority allocated nearly 50MHz to DSRC near 5.9 GHz. The main concept is shown in Figure 2. Until 2020, DSRC has popularly been used in a bus system for warning before intersections collisions and Cooperative Adaptive Cruise Control. In Singapore, this technology has been used mainly in electronic road pricing. Many countries follow this traffic management scheme because it can significantly reduce traffic conjunction and has correct efficiency of up to 85 percent.

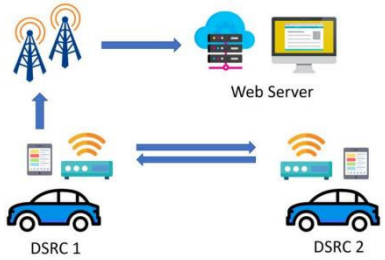


Figure 2. Dedicated Short Range Communication [3]

WLAN also have high performance in short-distance wireless communication famous for high data rate but limited by a short distance (nearly half of DSRC). Short-distance wireless communication follows IEEE 802.11 rule published in 1997.

Different from a short distance, long-term distance wireless communication LTE (Long Term Evolution) is defined by 3GPP which later confirmed not satisfied 4G communication requirements. Nowadays, 5G has developed since 2019 and has large potential help to ITS. uplink and downlink latency has been reduced, and security checks can add to Vehicle and network (V2N) to ensure accuracy like V2V. Figure 3 and Figure 4 shows the difference between network connect and direct connect. In summary, the 5G application has a large dependence on base station coverage, the technology will be more reliable when infrastructures get improved.

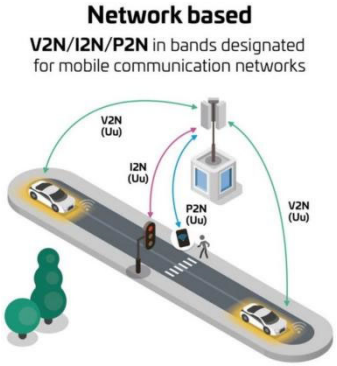


Figure 3. Internet Network Connect. [4]

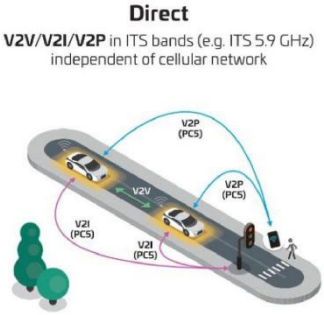


Figure 4. Direct Network [4]

4. Reduce road traffic by platoon

PLATOON is defined as using a minimum safety gap on roads. A PLATOON is made up of many electric vehicles that follow one another with a predetermined time headway [5], with the use of V2V communication. V2V provides rapid status updates of vehicles outside the line of sight, complementing existing onboard sensors like radar and camera. In [6], the authors investigate the safety of braking in platoon-like vehicle formations using a simplified assumption regarding continuous V2V communication delays [7]. shows that when one vehicle sends the braking information, only milliseconds are taken for other vehicles to brake in a platoon. Platooning has a tremendous deal of potential to improve efficiency and traffic safety [8] provides the safety analysis and explains in detail that the communication delays need to be smaller than a maximum to avoid collisions in platooning. Many conditions have been considered in [8] including the speed of the vehicles, the separation distance between two vehicles, the vehicle's acceleration capability, and the vehicle-to-vehicle communication time.

Figure 5 shows the truck platooning system where only the first vehicle is manual driving. The second and third vehicle is driven autonomously. To detect the current position and the environment, the vehicles use some sensors as well as cameras to collect information around vehicles. The

autonomous driving algorithm does not rely on GPS since the following vehicle (FV) cannot always get accurate GPS signals when travelling through tunnels [9].

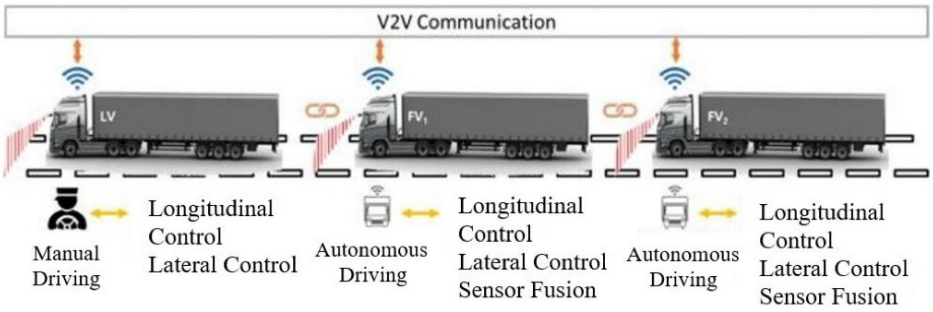
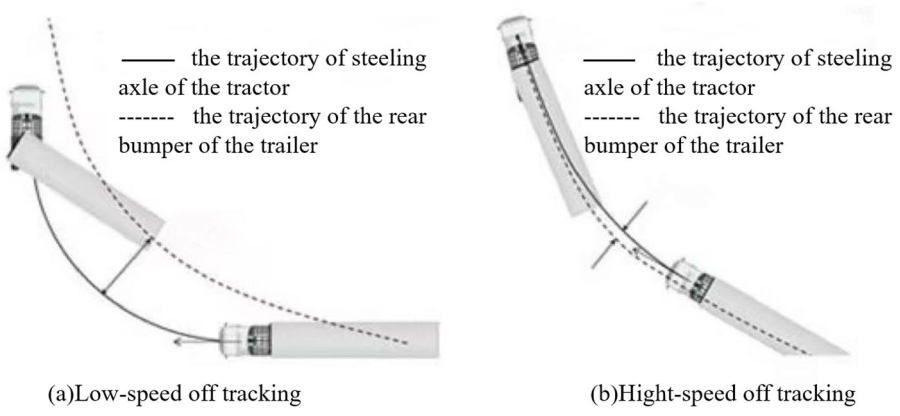


Figure 5. Truck Platooning [9]

Off-tracking may occur as depicted in Figure 6 [10] when vehicles are travelling through a curving road and turning, especially when tractor-and-trailer trucks are involved. To address this issue, [10] introduces a path planning algorithm, and Algorithm 1 (shown in Table 1) from [10] illustrates the path planning algorithm's workflow.



(a)Low-speed off tracking (b)Hight-speed off tracking

Figure 6. High and Low-Speed Platooning [10]

Table 1. Algorithm 1: Path Planning algorithm [10]

Input: TF.LV: Trajectory of "Front" point in LV'S coordinate TR.LV: Trajectory of "Rear" point in LV'S coordinate, Dataset P TR. FV: Trajectory of "Front" point in LV'S coordinate, Dataset Q [xR.LV yR.LV]: Coordinate of LV'S "Rear" point at current sample Output: TF. FV:Trajectory of "Front" point in FV's coordinate system Find the reference points p0,q0 using [xR.LV yR.LV] Translate the trajectories to coincide with the origin with the origin of FV's local coordinate system P1=P-po.w,Q1=Q-q0.w,w, weight matrix Find the rotation matrix and translation matrix H=P1.Q1 covariance matrix [U,S,V]=svd(H) singular value decomposition D 2-by-2 diagonal matrix If |V.U^t|<0,then D (2,2)=-1, return D: End R=V.D. U^t rotation matrix T=q0-R.po translation matrix Compute the target path TF. FV TF.LV using R and T Return TF. FV

When a car enters the motorway, it must look for other candidates to see if there is a platoon. Then the car needs to decide either to join the platoon or form a new platoon itself. It introduces two solutions to platoon formation challenges. For the centralized approach, a central server is used to collect the information of all cars through networks at the same time. Then a decision of matching will be made and sent to the car. For the distributed approach, cars are transmitting directly to other cars rather than the central server. By comparing both approaches, the centralized approach contains more information about cars. The benefit of this is that fewer join tactics will fail. The distributed approach is marginally inferior in time-consuming.

5. Routing network comparison

Lin-Kernighan-Helsgaun-3 (LKH-3) is an extension of LKH-2 and one of the best ways to solve the travelling man salesman problem. Besides that, it's also a convenient way of routing networks. Figure 7 shows the main concept of LKH is repeating until finding the route with minimum value.

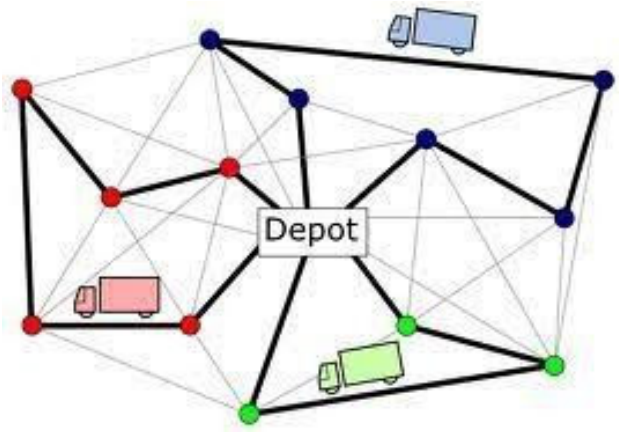


Figure 7. Lin-Kernighan-Helsgaun-3 [12]

Multi-Agent Routing Value Iteration Network (MARVIN) based on Vehicle to the Internet connection. The main goal is to keep updating the existing map and have a positive impact on autonomous driving and self-driving vehicles. There are two main challenges in MARVIN: The first one is the overload of the network during network connection which could cause the system failure, the second one is security, the address data couldn't get encoded which could cause the leakage of agent data.

MARVIN transmission process is separated mainly into three steps: First, get the current address of multi-agents, then process to iteration process. The address data needs repeat to implement a path graph but iteration also interference nodes accuracy before transmission. In the last step in the transmission process, data will be encoded and ready to send. Large data set is essential for MARVIN. Figure 8 shows agents intersection paths (larger than 10) experienced by Uber company.



Figure 8. Mapping [21]

In addition, MARVIN can use imitation learning or reinforcement learning methods. The imitation learning method uses teacher forcing. The reinforcement learning method uses agents and gains feedback according to agents' situations. Reinforcement learning feedback reduces transporting time and improves vanilla policy gradient. Algorithm 2 (shown in Table 2) shows the probability of action purpose for higher feedback [13].

Table 2. Algorithm 2: Vanilla Algorithm

Input: initial policy parameters a0, initial value function parameter b0
For k=1,2,3…do
Collect set of trajectories, Dk={t} by running policyπk=π(a0) in the environment
Compute reward to go Rt
Compute advantage estimates Ai (using any method of advantage estimation) based on the current function V.
Estimate policy gradient as
gk=1/(|Dk|) *Σ(r-Dk) Σ(t=0-T) ▽alog*π(at|st)|ak At*
Compare policy update, either using standard gradient ascent
A(k+1) =ak+akgk
Or via another gradient ascent algorithm like Adam.
Fit value function by regression on mean-suqared error:
B(k+1) = arg in 1/(|Dk|T) *Σ(r-Dk) Σ(t=0-T) (V(st)-Rt)^2
Typically, via the same gradian descent algorithm
End for

Figure 9 shows Graph Attention Network (GAT), which is mentioned in recent years related to the neural network, GAT uses the method by multiplying part of the matrix by the corresponding matrix and generated parameters. The key benefit is the stability because low data capacity requirement and fixed number of parameter output. According to these benefits, GAT is considered another potential method for routing networks.

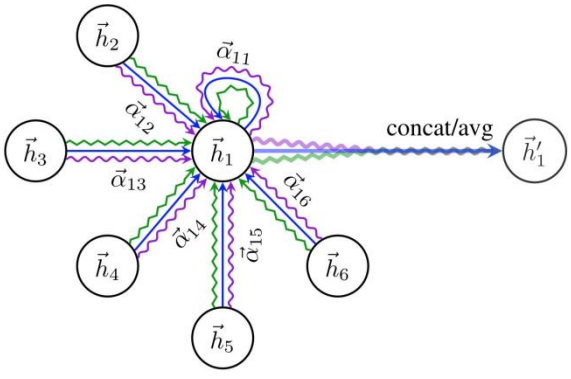


Figure 9. Graph Attention Network [14]

Generalized Value Iteration Network (GVIN) is an end-to-end network. With the help of convolution technology, GVIN gets improved quickly in real situations. By a mortifying Q-learning algorithm, VIN performs good results, especially in the unseen graph. Figure 10 shows the main concept of GVIN.

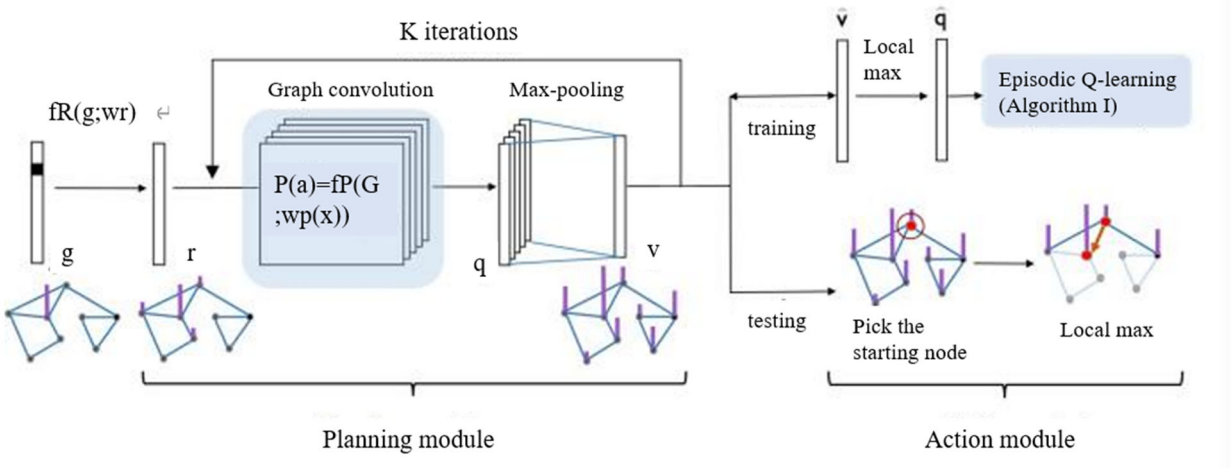


Figure 10. Generalized Value Iteration Network [15]

There are multi-agent route network testing results from 2 different groups. Figure 11 compares MARVIN(Green) GVIN(Blue) and GAT(Orange). Table 3 illustrates LKH3 MARVIN (imitate learning) and MARVIN (reinforcement learning) from cost, the gap between real map and runtime perspectives experiment by multi-agent (5) and pass through 100 intersections.

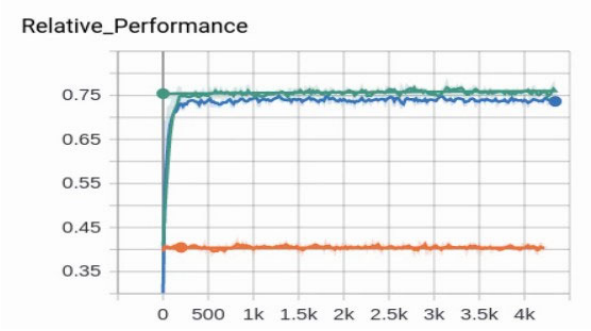


Figure 11. Comparison Graph [16]

Table 3: Different routing method comparison [15]

Method	Cost	Gap (real map)	Runtime (ms)
LKH-3	6.14	92.5%	2430
MARVIN(IL)	4.36	36.7%	72.8
MARVIN(RL)	4.62	44.9%	72.8

6. Conclusions

This paper investigated a platoon of vehicles to solve current transport challenges mainly in traffic security. The platoon can help adjust the safe distance in time which improves road efficiency using the V2V communication technique. This paper also investigates the routing network based on V2V and V2I techniques, which can provide up-to-date mapping that helps autonomous and manual drivers.

Overall, PLATOON help reduces fuel and reduce transport time significantly. Besides that, the MARVIN route network is competitive with other techniques to GAT and LKH3. In the current 5G background, V2I is still hard to achieve because of the requirement of a large data rate and low latency.

In future work, engineers will put more dangerous situations into consideration by platooning like one car before breaking- down or merging on the highway in a short time. For routing networks, engineers will investigate large data transfers and reduce expenses.

References

[1] Marc Torrent-Moreno; Jens Mittag; Paolo Santi; Hannes Hartenstein, "Vehicle-to-Vehicle Communication: Fair Transmit Power Control for Safety-Critical Information," IEEE Transactions on Vehicular Technology, (2009).

[2] Syed Sarmad Shah, Asad Malik , Anis Ur Rahman , Sohail Iqbal, "Time Barrier-Based Emergency Message Dissemination in Vehicular Ad-hoc Networks,"IEEE Access,pp.99,(2019).

[3] Yiyi Zhang, Yi Liu, Longfei, Xu ," A Real-Time Channel Prediction Model Based on Neural Networks for Dedicated Short-Range Communications, "Sensors,(2019).

[4] Stefan Ried, "5G killer App V2X" [Online]. Available: https://www.cloudflight.io/en/blog/5g-killer-app-v2x-requires-the-transformation-the-automotive-industry/.(accessed:28.07.2022)

[5] A. Vinel, L. Lan, and N. Lyamin, "Vehicle-to-vehicle communication in C-ACC/platooning scenarios," IEEE Commun. Mag., vol. 53, no. 8, pp. 192–197, (2015).

[6] L. Xu, L. Y. Wang, G. Yin, & H. Zhang, "Communication information structures and contents for enhanced safety of highway vehicle platoons," IEEE Trans. Veh. Technol., vol. 63, no. 9, pp. 4206–4220, (2014).

[7] D. K. Murthy, & A. Masrur, "Exploiting space buffers for emergency braking in highly efficient platoons," in Proc. IEEE 23rd Int. Conf. Embedded Real Time Comput. Syst. Appl. (RTCSA), Hsinchu, Taiwan,(2017), pp. 1–10.

[8] Julian Heinovski; Falko Dressler, "Platoon Formation: Optimized Car to Platoon Assignment Strategies and Protocols,"IEEE Vehicle Networking,(2018).

[9] Thunberg, Johan., Lyamin, Nikita., Sjoberg, Katrin, & Vinel, Alexey,"Vehicle-to-Vehicle Communication for Platooning: Safety Analysis," IEEE Networking Letters,(2019)

[10] Lee, Y., Ahn, T., Lee, C., Kim, S., &Park, K. "A Novel Path Planning Algorithm for Truck Platooning Using V2V Communication, Advanced Sensing and Control for Connected and Automated Vehicles (2020).

[11] Julian Heinovski; Falko Dressler, "Platoon Formation: Optimized Car to Platoon Assignment Strategies and Protocols,"IEEE Vehicle Networking,(2018).

[12] K. Helsgaun, "An Extension of the Lin-Kernighan-Helsgaun TSP Solver for Constrained Traveling Salesman and Vehicle Routing Problems," Technical Report, (2017).

[13] O. AI. (). "Vanilla policy gradient," [Online]. Available: https://spinningup.openai.com/en/latest/algorithms/vpg.html. (Accessed: 25.07.2022).

[14] Giuseppe Futia , "Graph Attention Networks Under the Hood" [Online]. Available: https://towardsdatascience.com/graph-attention-networks-under-the-hood-3bd70dc7a87.(accessed:25.07.2022)

[15] Hunag Yu, "Vehicle to Vehicle Communication for self-driving" [Online]. Available: https://zhuanlan.zhihu.com/p/406951048.(accessed:28.07.2022)

[16] Quinlan. Sykora. (). "Multi-agent routing value iteration network (Marvin)," [Online]. Available: https://github.com/uber-research/MARVIN/blob/master/README.md. (Accessed: 24.07.2022).